INNOVATIVE AND ENERGY EFFICIENT LIGHTING TECHNOLOGY

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Abstract - *Lighting plays a crucial role in regulating human physiological processes as well as visual performance and safety. Lighting is an essential component influencing the quality of life as well as the efficiency of our workforces. But in the current scenarios, more energy is consumed by the lighting systems in housing and commercial environment. Energy-efficient lighting can be achieved by substituting high power-consumption lights, such as incandescent and high discharge lamps, with those that produce greater illumination from fewer sources. Usage of energy efficient lights such as CFL and LEDs were already adopted, even though more energy is getting wasted by the lighting system. Therefore, adapting energy efficient lighting systems along with motion sensor can reduce energy consumption. The present study aims to research various methods of decreasing the global footprint as well as to provide sustainable and feasible technologies for improving energy efficient lighting. The study identifies various innovative and energy efficient lighting technologies with different motion sensors depending upon their environment with the help of case studies. From the compared case studies, we can conclude that lighting technology with motion sensors is an effective energy efficient lighting method. Use of motion sensors along with energy efficient lighting reduces energy consumption and global footprint and saves more energy.*

Key Words: Lighting, energy efficiency, LED, motion sensors, smart lighting

1.INTRODUCTION

In modern culture, lighting is expected to do more than just provide illumination; it is also anticipated to be environmentally friendly. Because energy is limited and environmental concerns are becoming more significant, there is an increasing need for high-efficiency lighting systems. Energy efficiency, lifetime, light output, and distribution, along with extremely small sizes and consequently extreme flexibility of use, colour quality, colour shift, and dimmability, are potential areas for improvement in lighting technology. **(Ayesha Muneeb, 2017)**

Researchers have focused on examining the usability and efficiency of various smart lighting systems that are currently on the market, particularly for private homes, offices, and public streets. **Füchtenhan *et al.,* 2021**. Light emitting diodes (LEDs), a newly developed lighting technology, are already a common source of illumination.

According to **Gentile *et al.,* 2021**, LEDs have a significant potential for energy savings. Energy consumption can be further decreased when LEDs are coupled with an intelligent light control system (which may, for example, use innovative motion and occupancy sensors).

Modern sensor technology has greatly advanced and can now take precise measurements under a wide variety of circumstances. Sensor is a device that transforms an input signal from a stimulus into a readable output signal, with the output ultimately being an electrical signal. Any measurable characteristic, like quantity or physical variation, can be the input signal.

Business, residential, industrial, and outdoor lighting are all different types of lighting. Each industry has specific lighting requirements and wants, which are met by using various sensors. Ambient sensors will be used as a low-cost, simple solution because the residential sector wants to use less power.

1.1 BACKGROUND OF THE STUDY

A significant portion of global electricity consumption is used for lighting. This is because it has been used for a very long time and is a crucial component of any building. In order to operate the power management system by wire, additional equipment and installation costs for a separate wiring system are needed. Therefore, it is essential to create a system that can be controlled wirelessly. An important component for enabling the application to daily life, including uses like building and home automation, is the lighting control system based on wireless sensor network. In India, as per 2018, 18% of the electrical energy is consumed for lighting. If lighting methods are evolved, this amount can be reduced to a greater extent. In this study, different methods are proposed for saving electricity and also for improving lighting technology.

1.2 PROBLEM STATEMENT

About one-fifth of all electricity used worldwide is for lighting. Building lighting systems can use up to 30% of all energy consumed. As the population, lifestyle, and technological advances change, so does the demand for energy. Using efficient lighting technologies can potentially save significant amounts of energy by reducing the energy consumption caused by artificial lighting. Customers' visual comfort (pleasant environments, accurate colour reproduction, comfortable colour temperature, etc.) should be provided by the lighting system in addition to operational performance and economics.

1.3 AIM, OBJECTIVES AND SCOPE OF THE STUDY

Lighting is an essential component influencing the quality of life as well as the efficiency of our workforces. This study aims to research various methods of decreasing the global footprint of lighting as well as provide sustainable and feasible suggestions for improving energy efficient lighting.

To mitigate the demand for lighting, energy efficient and innovative ways of lighting is the need of the hour. With the methods being suggested in the dissertation, efficient lighting technology can be employed in all the buildings which will reduce the amount of electricity consumed providing energy efficiency which in turn reduces the global footprint. Developing countries like India should adopt these methods and stand as an example for other countries. Energy efficient methods are so powerful as in the switching of conventional bulbs to LEDs has almost reduced 50% electricity consumption across India.

The scope is to locate effective lighting systems in the market and discover energy-efficient methods to optimize their performance to reduce costs. Additionally, the identified techniques will be assessed for their Return on Investment (ROI), and recommendations will be provided to enhance the energy efficiency of the lighting system.

2. METHODOLOGY

In this research, previously published journals are analyzed by literature review and various case studies were compared where different lighting technologies were implemented. Live case studies were also compared and the best lighting technology was identified using the gathered information. Then the site for implementation of the research plan was selected and the identified best (LED) lighting technology along with motion sensors was installed. The cost estimation and payback period were evaluated.

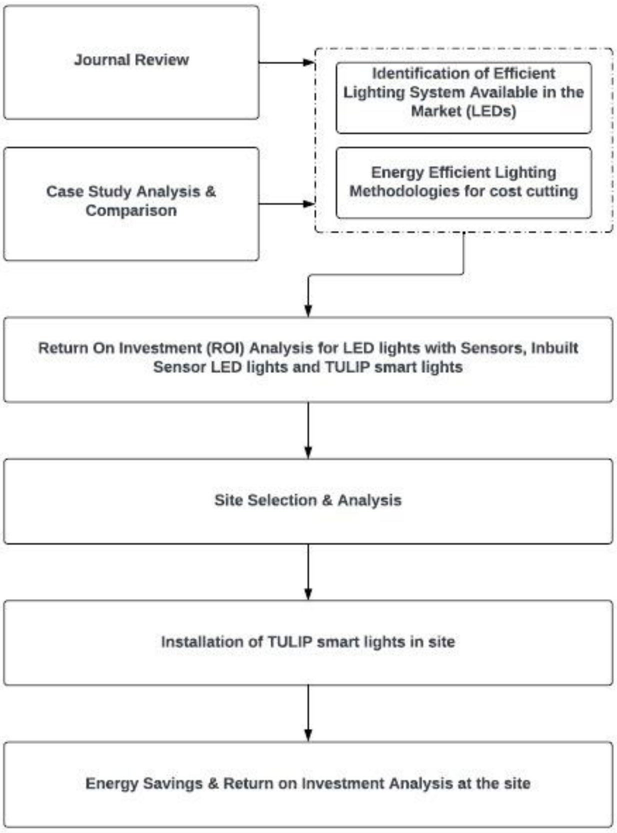


Chart- 1: Methodology

3. LITERATURE REVIEW

Many researches had been done to identify best lighting technology. Previously published journals between the year of 2007 and 2022 were studied and using the gathered information best lighting technology was chosen in terms of energy efficiency.

Installations for public lighting are a significant consumption in smart cities. Implementing energy-saving measures is thus necessary. Energy efficiency is one of the main goals of smart cities. In this regard, public lighting installations symbolizes a sizeable amount of energy consumption, influenced by things like regulation and maintenance. By utilizing innovative control and communication techniques, lighting installations' energy consumption can be decreased **(Sutil *et al.,* 2021)**

The SLR algorithm is a useful tool for increasing the energy efficiency of installations for public lighting. The ABC algorithm improves the SLR's response time and helps it adjust more quickly to the different lighting conditions that arise at different times. For this, it makes use of the OMDSL, which offers high resolution in data collection and transmission of the measured electrical variables over the LoRa LPWAN network and cloud storage using Firebase, enabling complete system monitoring **(Sutil *et al.,* 2021)**

Depending on the circumstances and events, sound levels can be used as a parameter to change the lighting levels. The ambient sound can be helpful in defining various scenarios for regulating the energy consumption of light sources. Energy consumption for light-emitting diodes (LEDs) can be reduced by more than 40% when environmental activity is reduced by factoring in sound levels. This technique also improves the precision with which people make decisions about the environmental factors of light and sound. This can be viewed as a novel way to manage the energy consumption of LED light sources while still meeting user needs in smart cities **(Kalani *et al.,* 2022)**

According to **Shahzad *et al.,* 2016**, the smart street lighting system can save 68% to 82% of energy depending on the differences in daylight hours between summer and winter when conventional metal halide lighting is replaced with traffic-flow based smart (LED) street lighting.

Energy efficiency improvement is challenging because lighting, both indoor and outdoor, uses a lot of energy. Smart public lighting control is a promising strategy for dealing with outdoor lighting **(Shahzad *et al.,* 2016)**

Using an effective ILACS control algorithm for intelligent LED indoor lighting systems, the brightness of the interior lights could be used to maximize energy savings by controlling the system in real-time when entering, in order to take advantage of daylight or external lighting **(Hong *et al.,* 2017)**

Smart-street lighting is a cost-effective solution for urban environments that combines innovative wireless communication technologies, inexpensive LED lights, and additional sensors that regulate light intensity. A motion detection smart lighting system was installed in place of the outdated 320 street luminaries and additional 63 LED lights in the Nagpur smart city case study. The smart city of Nagpur's implemented intelligent street lighting system has been found to significantly reduce energy consumption by about 55% each month while maintaining the lighting standards for pedestrians and vehicles **(Prasad, 2020)**

Muneeb, 2017 reported that LEDs are the upcoming technology that has been extensively promoted for its potential to save energy as well as its low energy consumption, longevity, efficiency, reliability, and ease of use in new and improved designs. By conducting a case study in a commercial set up it has been found that 47% of the energy had been saved using LED lighting. In the commercial sector, LED lighting is undoubtedly a viable alternative to conventional incandescent and CFL lighting.

Solar PV systems are a more trusted and suitable technology for light loads and isolated rural areas. Economically competitive solar photovoltaic systems are ideal for the widely dispersed rural areas **(Bhusal *et al.,* 2007)**

Control of daylight-adaptive lighting systems is known to be energy-efficient. Estimating daylight level presents a fundamental challenge in such control **(Yang *et al.,* 2012)**

4. NET CASE STUDIES

4.1 H University Campus, Seoul city, South Korea

Figure - 1: H University Campus

Lighting system used: LED lighting

Sensor used: RF sensor

Sensor description

Sensors were installed in underground parking lots, lecture rooms, and dormitories of the university building, to study the effect of a motion detection sensor and room management system on electricity consumption. Based on an assumption that the class timetable and working pattern were repeated similarly every morning, sensors were switched on and off on a weekly basis. The amount of electricity used for heating, cooling, and lighting, among other uses, was measured and compared with and without sensor operation.

Inference

From this it can be inferred that underground parking lots were able to achieve the greatest savings, followed by dormitories and then classrooms, which generally coincide with the time of operation of each setting. the average light energy saved by using the RF Sensor was 39.5 Wh/m2·day. Compared to not using the sensor, energy was conserved by 77.6%. Similar to this way regular offices or homes differ from universities in their load characteristics.

4.2 Nagoya University Campus, Japan

Figure - 2: Nagoya University Campus

Location and description

The case-study building for this project is a U-shaped combination office/laboratory/classroom building on the campus of Nagoya University. The 10 floors contain approximately 268 offices. Only the lights and exhaust fans in the restrooms and the hallways are controlled by occupancy sensors.

Motion sensor model

Lights in the lobby, hallways, and bathrooms are controlled by motion sensors and can be turned ON or OFF. There are three zones on separate motion sensors in corridors. In the hallway, a standard ceiling-mounted motion sensor.

Monte Carlo Technique

All of the lights in the hallways, lobby, and restrooms of the case study building are controlled by motion sensors. Additionally, they are in charge of the restrooms' exhaust fans and ventilation system. The simulation model was programmed with the Monte Carlo technique, and it was executed using the case study-derived parameters.

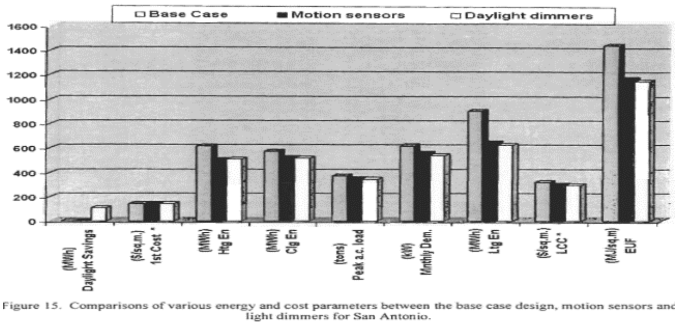


Figure - 3: Comparison of Use cases – Nagoya University

Inference

This study has demonstrated that there is high potential for significant energy savings when occupancy sensors are used in the public use areas of ' an office building in the hot humid climate examined. The Monte Carlo modelling method affords the opportunity of performing realistic simulations of the behaviour of motion sensors when brief statistics of the performance are collected in advance.

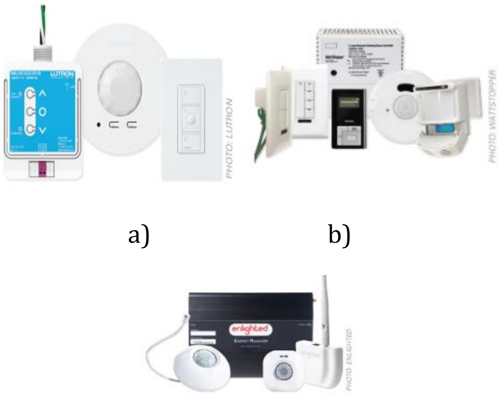
4.3 UCSF'S Mount Zion Medical Center, San Francisco

Figure – 4: UCSF'S Mount Zion Medical Center, San Francisco

Lighting system

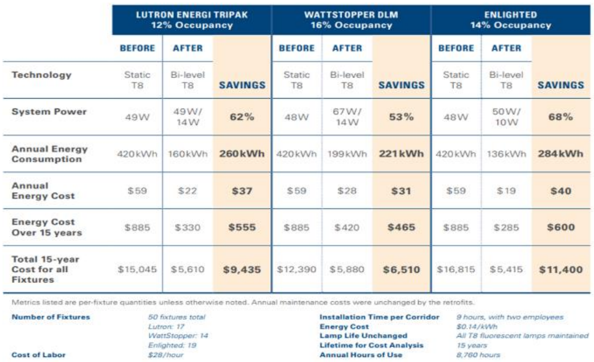
In three distinct UCSF corridors, three control systems were installed, each with a different system architecture. All three systems make use of occupancy controls, but they each offer a different degree of control, a variety of programming options, and features for tracking energy use and maintenance. Three control systems

- Lutron
- Watt Stopper
- Enlighted


a) b)

c)

Figure – 5: a) Lutron b) Wattstopper c) Enlighted



	LUTRON ENERGI TRIPAK 12% Occupancy			WATTSTOPPER DLM 16% Occupancy			ENLIGHTED 14% Occupancy		
	BEFORE	AFTER		BEFORE	AFTER		BEFORE	AFTER	
Technology	Static T8	Bi-level T8	SAVINGS	Static T8	Bi-level T8	SAVINGS	Static T8	Bi-level T8	SAVINGS
System Power	49W	49W/ 14W	62%	48W	67W/ 14W	53%	48W	50W/ 10W	68%
Annual Energy Consumption	420kWh	160kWh	260kWh	420kWh	199kWh	221kWh	420kWh	136kWh	284kWh
Annual Energy Cost	$59	$22	$37	$59	$28	$31	$59	$19	$40
Energy Cost Over 15 years	$885	$330	$555	$885	$420	$465	$885	$285	$600
Total 15-year Cost for all Fixtures	$15,045	$5,610	$9,435	$12,390	$5,880	$6,510	$16,815	$5,415	$11,400

Metrics listed are per-fixture quantities unless otherwise noted. Annual maintenance costs were unchanged by the retrofits.

Number of Fixtures	*50 fixtures total* *Lutron: 17* *WattStopper: 14* *Enlighted: 19*
Cost of Labor	*$28/hour*
Installation Time per Corridor	*9 hours, with two employees*
Energy Cost	*$0.14/kWh*
Lamp Life Unchanged	*All T8 fluorescent lamps maintained*
Lifetime for Cost Analysis	*15 years*
Annual Hours of Use	*8,760 hours*

Figure – 6: Demonstration Results

Demonstration results

Lutron - The installation of Lutron reduced lighting energy consumption by 62%, resulting in 260 kWh in annual savings (occupancy rate: 12%).

Wattstopper - The WattStopper installation saved 3,108 kWh annually (occupancy rate: 16%) by reducing lighting energy use by 53%.

Enlighted - With a 14 percent occupancy rate, the Enlighted system saved 68% of its annual energy consumption, or 5,396 kWh.

Inference

The UCSF lighting management systems installed represent a variety of approaches, from traditional to cutting-edge. Facilities with limited funding or lower electricity rates may find it necessary to select a system with lower up-front costs. Less costly systems do not offer all the features of systems that can be customized, but they achieve a large percentage of the energy savings that can be realized with corridor lighting retrofits.

4.4 University of California, Santa Barbara

Figure – 7: University of California

Sensing technology

The California Lighting Technology Centre (CLTC) and Adura Technologies collaborated to develop the wireless integrated photosensor and motion detection (WIPAM) system, which uses wireless communications to get around the challenging wiring issue and expands the number of buildings that could affordably benefit from lighting controls. The Adura Light Point System makes it possible to install control parts in both existing and newly constructed luminaires. This was tested in the parking lot of the university.

Figure – 8: Photo sensor

Pre-retrofit, traditional solution with wired sensor (WIPAM), post retrofit solutions were developed and tested.

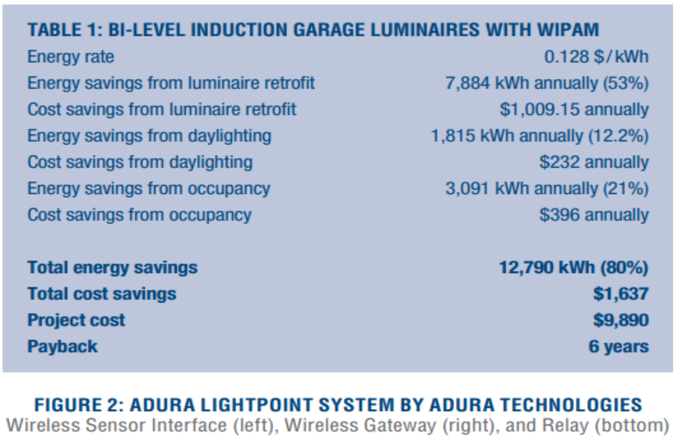


TABLE 1: BI-LEVEL INDUCTION GARAGE LUMINAIRES WITH WIPAM

Energy rate	0.128 $/kWh
Energy savings from luminaire retrofit	7,884 kWh annually (53%)
Cost savings from luminaire retrofit	$1,009.15 annually
Energy savings from daylighting	1,815 kWh annually (12.2%)
Cost savings from daylighting	$232 annually
Energy savings from occupancy	3,091 kWh annually (21%)
Cost savings from occupancy	$396 annually
Total energy savings	**12,790 kWh (80%)**
Total cost savings	**$1,637**
Project cost	**$9,890**
Payback	**6 years**

FIGURE 2: ADURA LIGHTPOINT SYSTEM BY ADURA TECHNOLOGIES
Wireless Sensor Interface (left), Wireless Gateway (right), and Relay (bottom)

Figure – 9: Benefits of sensor-controlled lighting

Inference

The retrofit resulted in annual energy savings of 12,790 kWh and a 900 W decrease in energy demand. This translates to a simple payback period of six years and annual savings in energy of about $1,600.

5. NET CASE STUDY COMPARISON

S.NO	CASE STUDY DONE AT	LIGHTING TYPOLOGY	TYPE OF SENSOR USED	METHODOLOGY	ENERGY SAVINGS	CONCLUSION
1	Hotel Service Apartment at JVT Dubai, U.A.E.	Corridors	Motion sensors	In the residential tower, for 13 floors (so 13 corridors), 12 light bulbs were fitted with motion sensors and 2 bulbs were always switched ON	Energy savings were interpreted cost wise. It was witnessed that annually, 1.65 lakhs in Indian Rupees can be saved by using this methodology	Even though there is initial fitting and maintenance costs, the energy savings can be achieved later. The motion sensors provide good lighting energy savings.
2	Pacific Gas and Electric Company, San Francisco	Office Interior working spaces	Occupancy sensors (switch ON/OFF control) and Daylight Harvesting (Dimming effects)	Five phases of savings done. P1 - Manual Control, P2- Manual Dimming of lights, P3 - Dimming with Daylight Harvesting, P4 - Occupancy Sensors Controlling Lights, P5 - Both Occupancy and Daylight.	Energy savings were interpreted cost wise in each phase. The most savings were found in Phase 4 with Occupancy sensors. The simple payback period for Phase 5 is 12.6 years.	Energy savings were accumulated for each phase and different scenarios were tested in phases. The best scenario was found and fully functional energy savings system was implemented.
3	UBL University, Indonesia	Restrooms	Infrared Motion sensors	In 6 restrooms, motion sensors were fitted in the university and lighting savings were observed.	40% energy savings guaranteed with installation of infrared motion sensor. Base measurement yields power consumption of 55.576 kWh, with base electricity fare of 1.467,28 Rp/kWh; this costs Rp 327.356,04 per month or Rp 23.6 million annually for 6 restrooms.	The expected reduction of 40% is firmly achieved after 14 hours of operation, and after 28 hours, it only consumes half than without sensors for the same duration. The first phase of implementation on restrooms yields a cost saving of Rp 15 million
4	Microwave Motion Sensors	Industrial Warehouse, Parking Area,	Microwave Motion Sensors and TULIP Smart Lights	In Industrial Warehouse, 300 lights fitted with sensor. In parking Area, 300 lights plus 150 sensors were fitted.	Energy savings with payback period of 18 months, 9 months were given for Warehouse, Parking area respectively.	New smart lights like TULIP and sensors with microwaves detection were experimented and found to give good savings.

Table – 1: Case study comparison

6. SITE STUDY

6.1 SITE STUDY SELECTION AT TRICHY

ARISTO SARAVANA RESIDENCY, TRICHY

Figure – 10: Aristo Saravana Residency, Trichy

Location and description

Aristo Saravana Residency is situated in Trichy, Tamil Nadu. It is a stilt + 4 structure with R.C.C Framed structure with Light Weight block of 230mm for external wall and 150mm for internal partition wall. Height of each floor in the building is 3m. Client- M/S Saravana Shelters. Area – 20500sqft. Total no of Units – 60units (15units per floor – 9units were 2BHK, 6units were 3 BHK). Total number of dwelling units per floor – 15 units. 2BHK – 9 units, 3Bhk – 6 units. The corridor is well ventilated with OTS

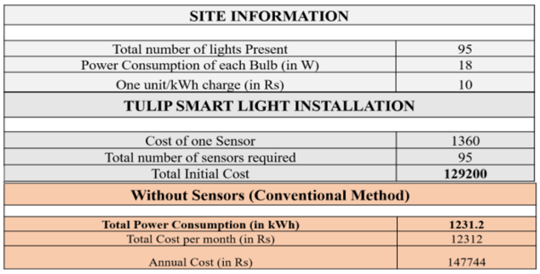
Floor plan

Figure – 11: Floor plan of Aristo Saravana Residency

Results of implementation

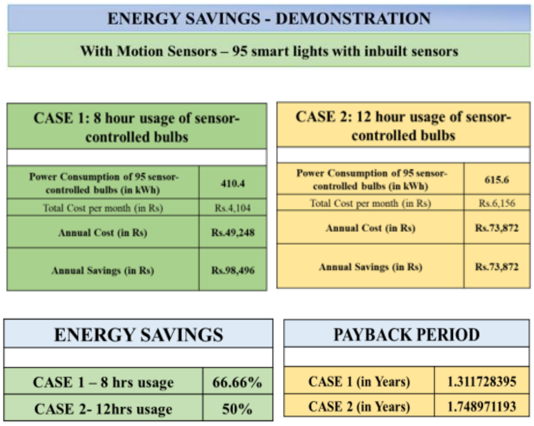
Experiment 1

Parking area



SITE INFORMATION	
Total number of lights Present	95
Power Consumption of each Bulb (in W)	18
One unit/kWh charge (in Rs)	10
TULIP SMART LIGHT INSTALLATION	
Cost of one Sensor	1360
Total number of sensors required	95
Total Initial Cost	**129200**
Without Sensors (Conventional Method)	
Total Power Consumption (in kWh)	**1231.2**
Total Cost per month (in Rs)	12312
Annual Cost (in Rs)	147744

Table – 2: Exp 1 – Consumption Without Sensors



ENERGY SAVINGS - DEMONSTRATION

With Motion Sensors – 95 smart lights with inbuilt sensors

CASE 1: 8 hour usage of sensor-controlled bulbs	
Power Consumption of 95 sensor-controlled bulbs (in kWh)	**410.4**
Total Cost per month (in Rs)	Rs.4,104
Annual Cost (in Rs)	**Rs.49,248**
Annual Savings (in Rs)	**Rs.98,496**

CASE 2: 12 hour usage of sensor-controlled bulbs	
Power Consumption of 95 sensor-controlled bulbs (in kWh)	**615.6**
Total Cost per month (in Rs)	Rs.6,156
Annual Cost (in Rs)	**Rs.73,872**
Annual Savings (in Rs)	**Rs.73,872**

ENERGY SAVINGS	
CASE 1 – 8 hrs usage	66.66%
CASE 2- 12hrs usage	50%

PAYBACK PERIOD	
CASE 1 (in Years)	1.311728395
CASE 2 (in Years)	1.748971193

Table - 3: Energy Savings with 8 and 12 hours sensor Usage

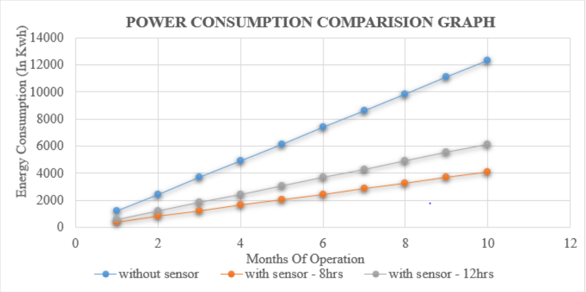
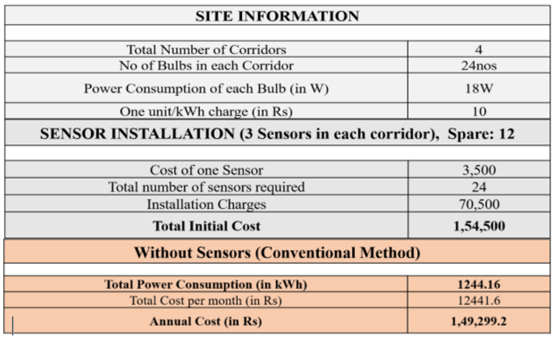


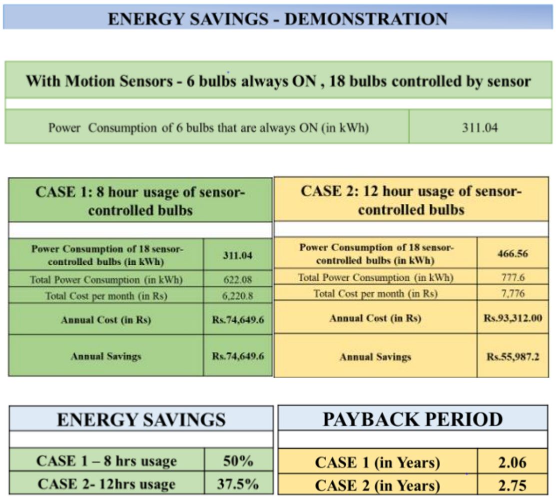
Chart – 2: Energy Consumption Comparison Graph

Experiment 2 Corridors and Staircase



SITE INFORMATION	
Total Number of Corridors	4
No of Bulbs in each Corridor	24nos
Power Consumption of each Bulb (in W)	18W
One unit/kWh charge (in Rs)	10
SENSOR INSTALLATION (3 Sensors in each corridor), Spare: 12	
Cost of one Sensor	3,500
Total number of sensors required	24
Installation Charges	70,500
Total Initial Cost	**1,54,500**
Without Sensors (Conventional Method)	
Total Power Consumption (in kWh)	**1244.16**
Total Cost per month (in Rs)	12441.6
Annual Cost (in Rs)	**1,49,299.2**

Table – 4: Exp 2 Consumption without sensors



ENERGY SAVINGS - DEMONSTRATION

With Motion Sensors - 6 bulbs always ON , 18 bulbs controlled by sensor	
Power Consumption of 6 bulbs that are always ON (in kWh)	311.04

CASE 1: 8 hour usage of sensor-controlled bulbs	
Power Consumption of 18 sensor-controlled bulbs (in kWh)	**311.04**
Total Power Consumption (in kWh)	622.08
Total Cost per month (in Rs)	6,220.8
Annual Cost (in Rs)	**Rs.74,649.6**
Annual Savings	**Rs.74,649.6**

CASE 2: 12 hour usage of sensor-controlled bulbs	
Power Consumption of 18 sensor-controlled bulbs (in kWh)	**466.56**
Total Power Consumption (in kWh)	777.6
Total Cost per month (in Rs)	7,776
Annual Cost (in Rs)	**Rs.93,312.00**
Annual Savings	**Rs.55,987.2**

ENERGY SAVINGS	
CASE 1 – 8 hrs usage	50%
CASE 2- 12hrs usage	37.5%

PAYBACK PERIOD	
CASE 1 (in Years)	2.06
CASE 2 (in Years)	2.75

Table – 5: Energy Savings With 8 and 12 hours sensor usage

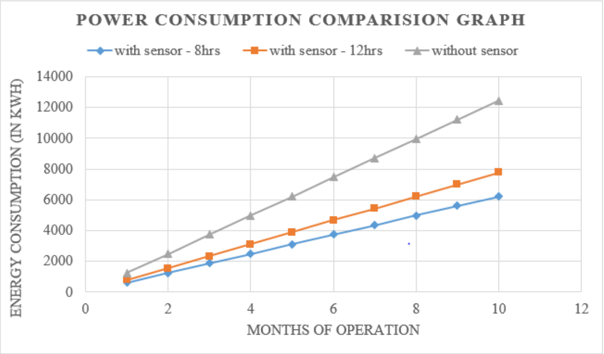


Chart – 3: Energy Consumption Comparison Graph

Inferences

From the results of previous research studies, energy and related cost consumption in the public spaces such as parking areas, corridors and staircase in a multistorey residential building can be saved with the implementation of the motion sensors & smart lights available in the market. Aristo Saravana Residency is an upcoming project in Trichy. It is chosen as the implementation site as the proposal for installation of motion sensors seems viable in this case. This research focuses on comparing the cost and energy differences between the conventional lighting methods and the innovative lighting technologies.

For our case, Motion sensors are used in Corridors and Staircases which on detecting motion will switch ON and OFF correspondingly. It will also have timer for continuous motion detection with default lighting time. TULIP smart lights are chosen for Parking Area which have dimming and motion detection features. This works well in Parking lots since lights cannot be switched off during nights. Instead, it will dim based on motion.

7. CONCLUSION:

From the demonstrations, it can be concluded that energy efficient installations prove worthy over the years of usage and save associated costs too. The trade-off between sensors/smart light installments and cost savings also lean towards the energy efficient installations. This can be proved with the payback periods of smart lights in parking area (1.75 years) and motion sensors in corridors/staircase (2.75 years) Best case scenario (Reduced energy consumption after installing sensors and TULIP lights) - High energy savings and faster payback period. Worst case scenario (Moderate energy consumption after installing sensors and TULIP lights) – Low energy savings with a considerable payback period. Even when we consider the worst-case scenario, we get energy savings that is beneficial in terms of environmental & economical aspect. So, to conclude, these installations prove worthy and can be implemented in all multistorey buildings.

8. RECOMMENDATIONS:

- Further studies can be done to reduce energy usage in commercial and public spaces by using various lighting technology.

- Motion sensors prove worthy and save lighting costs when implemented in multistorey buildings. The ROI looks good for these installations.

- TULIP Smart Lights are relatively new to market and can be installed in commercial buildings.

- Installing these sensors not only reduce lighting energy costs but also provide ecological advantages over conventional LEDs.

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